Jet Propulsion Laboratory
California Institute of Technology

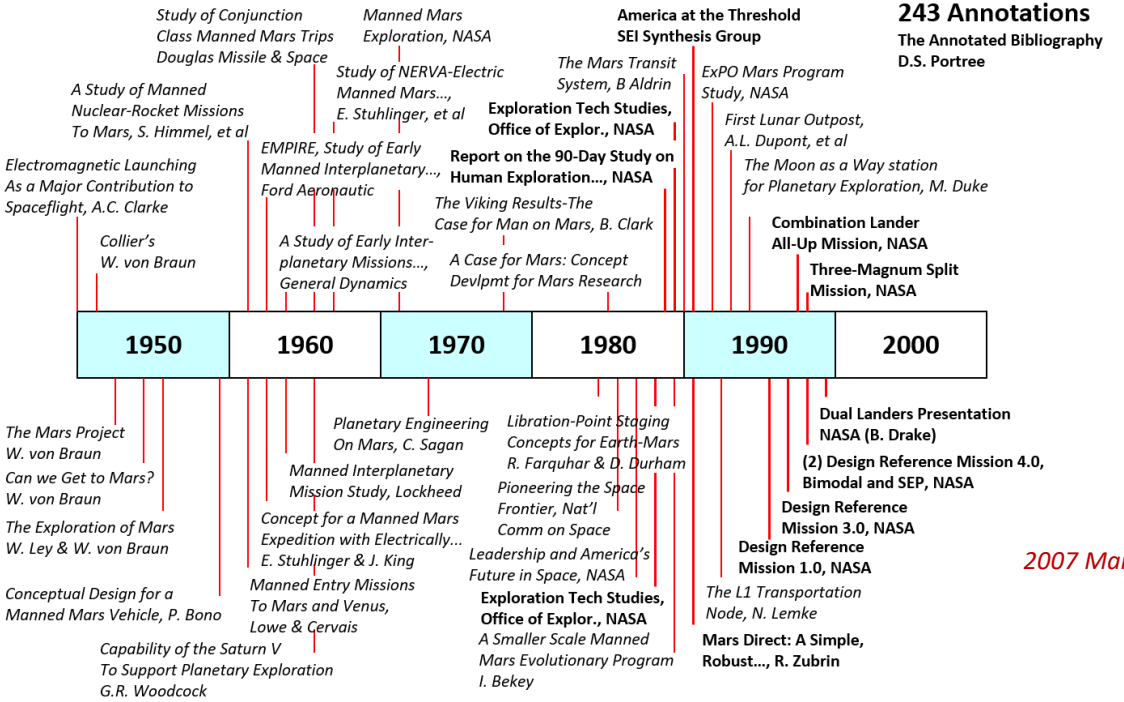
Selecting a Landing Site for Human Missions to Mars – An Overview of Current Activities and Open Trades

Presented by Sydney Do, Ph.D.

3rd Off-Earth Mining Forum, September 20, 2017, Sydney, Australia

The Past 60+ Years of Human Mars Mission Studies

Overview of major Mars mission planning: 1950-2000



Major NASA Studies since 1988

1988: NASA "Case Studies"

1989: NASA "Case Studies"

1990: "90-Day" Study

1991: White House "Synthesis Group"

1992-93: NASA Mars DRM1.0

1998: NASA Mars DRM3.0

1998-2001: Associated DRM3.0 Analyses

2002-2004: DPT/NExT

2007 Mars Design Reference Architecture 5.0

2009 Mars DRA5.0 Addendum

2014 Mars DRA5.0 Addendum #2

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Study of Conjunction Class Manned Mars Trips Douglas Missile & Space

Manned Mars Exploration, NASA

America at the Threshold SEI Synthesis Group

243 Annotations
The Annotated Bibliography
D.S. Portree

A Study of Manned Nuclear-Rocket Missions To Mars, S. Himmel, et al

Study of NERVA-Electric Manned Mars..., E. Stuhlinger, et al

The Mars Transit System, B Aldrin

ExPO Mars Program Study, NASA

Exploration Tech Studies, Office of Explor., NASA

First Lunar Outpost, A.L. Dupont, et al

Electromagnetic Launching As a Major Contribution to Spaceflight, A.C. Clarke

EMPIRE, Study of Early Manned Interplanetary..., Ford Aeronautic

Report on the 90-Day Study on Human Exploration..., NASA

The Moon as a Way station for Planetary Exploration, M. Duke

Collier's
W. von Braun

planetary Missions..., General Dynamics

A Case for Mars: Concept Deviopmt for Mars Research

Three-Magnum Split Mission, NASA

1950 | 1960 | 1970 | 1980 | 1990 | 2000

The Mars Project
W. von Braun

Can we Get to Mars?
W. von Braun

The Exploration of Mars
W. Ley & W. von Braun

Conceptual Design for a Manned Mars Vehicle, P. Bono

Capability of the Saturn V To Support Planetary Exploration
G.R. Woodcock

Planetary Engineering On Mars, C. Sagan

Manned Interplanetary Mission Study, Lockheed

Concept for a Manned Mars Expedition with Electrically...
E. Stuhlinger & J. King

Manned Entry Missions To Mars and Venus, Lowe & Cervais

Libration-Point Staging Concepts for Earth-Mars
R. Farquhar & D. Durham

Pioneering the Space Frontier, Nat'l Comm on Space

Leadership and America's Future in Space, NASA

Exploration Tech Studies, Office of Explor., NASA

A Smaller Scale Manned Mars Evolutionary Program
I. Bekey

Dual Landers Presentation
NASA (B. Drake)

(2) Design Reference Mission 4.0, Bimodal and SEP, NASA

Design Reference Mission 3.0, NASA

Design Reference Mission 1.0, NASA

The L1 Transportation Node, N. Lemke

Mars Direct: A Simple, Robust..., R. Zubrin

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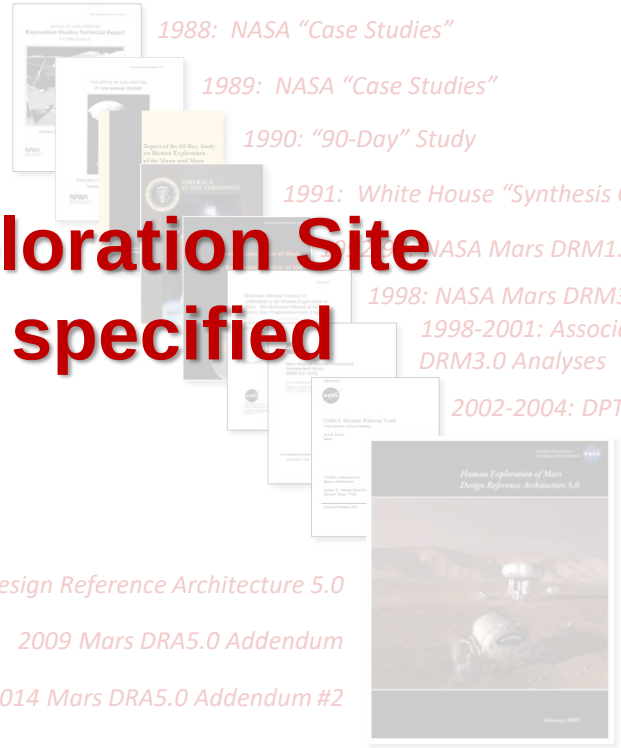

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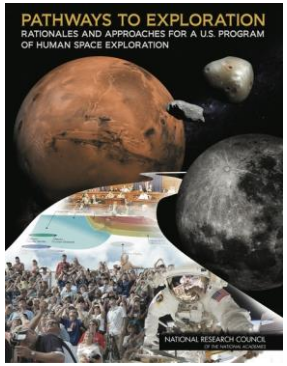
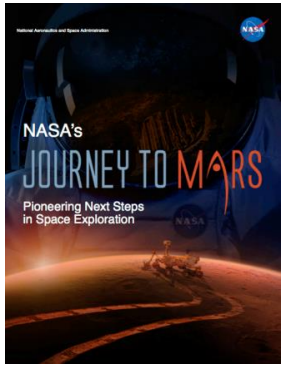
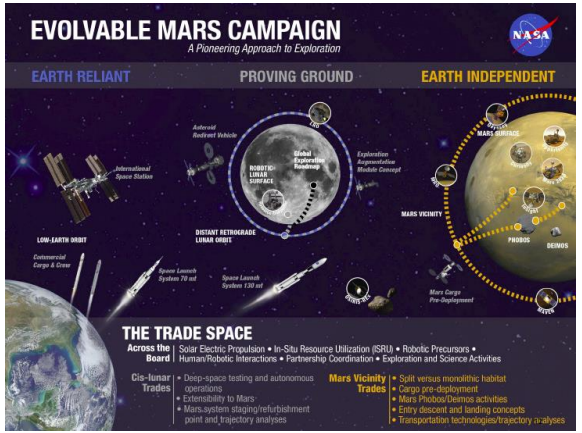
Specific Landing and Exploration Site on Mars not studied or specified

Why are we so interested in landing site selection today?

- **2010 NASA Authorization Act:** "The long term goal of the human space flight and exploration efforts of NASA shall be to expand permanent human presence beyond low-Earth orbit"
- **Fall 2012–June 2014**: National Academies Committee on Human Spaceflight studies sustainable paths forward for human spaceflight. Releases "Pathways to Exploration" Report, declaring that: "the 'horizon goal' for human space exploration is Mars"
- **April 2014**: NASA's "Journey to Mars" is announced, leads to the Evolvable Mars Campaign series of mission architecture studies
- **October 2015**: NASA releases "Journey to Mars" report, outlining the high level strategy and policy guidelines for developing a sustainable human Mars exploration program
- **NASA Transition Authorization Act of 2017**: "The key objectives of the United States for human expansion into space shall be… to achieve human exploration of Mars and beyond…"

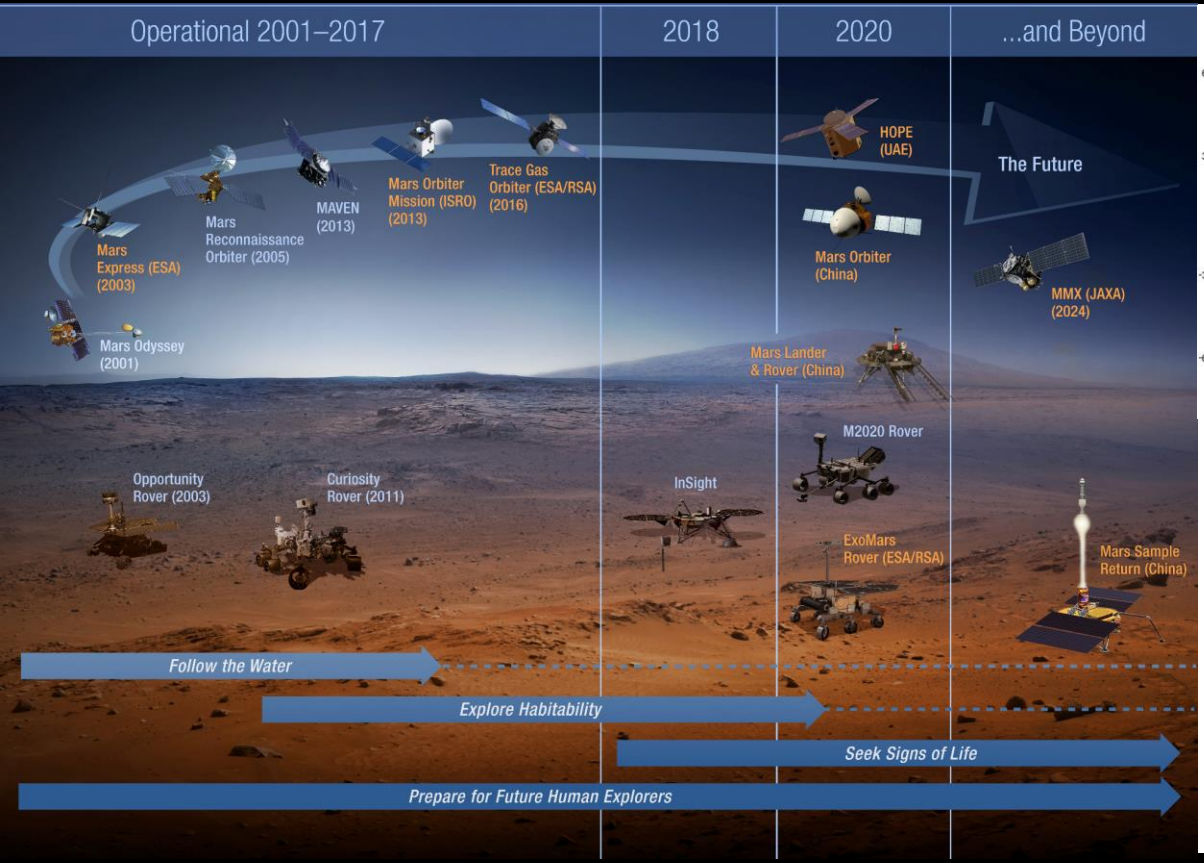


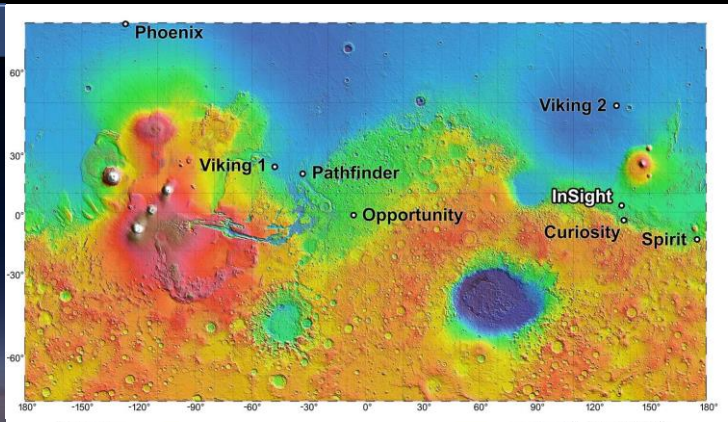


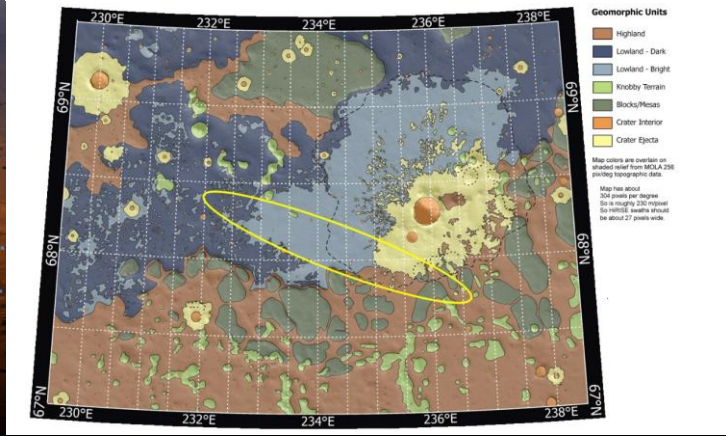


We've done this before!

20+ years of continuous robotic exploration of Mars

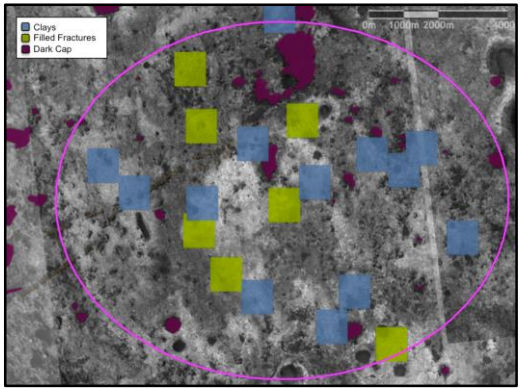


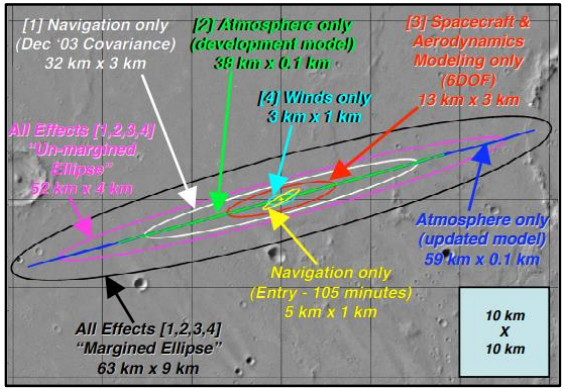


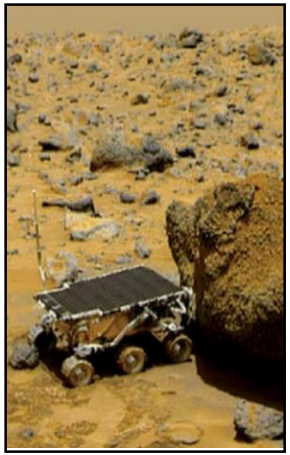


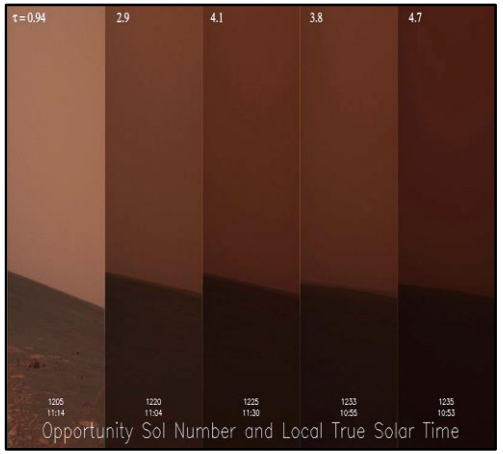
Landing Site Selection for Mars Rover Missions

- **Driven primarily by science value**
  - Maximize number and diversity of science regions of interest
- **Engineering constraints**
  - Landing safety
    - Atmospheric temperature and pressure, winds, site altitude, local rock distribution, slope of local terrain, lighting
  - Rover survival
    - Landing site season, insolation, likelihood of dust storms
  - Rover traversability
    - Rock distribution, slopes, terrain type



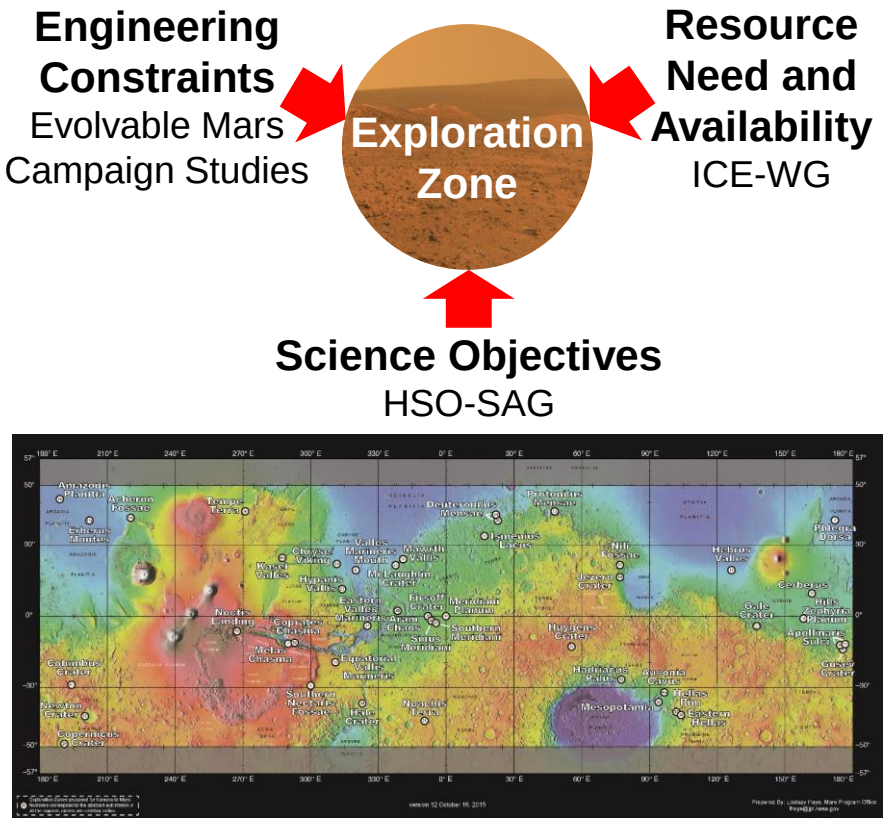






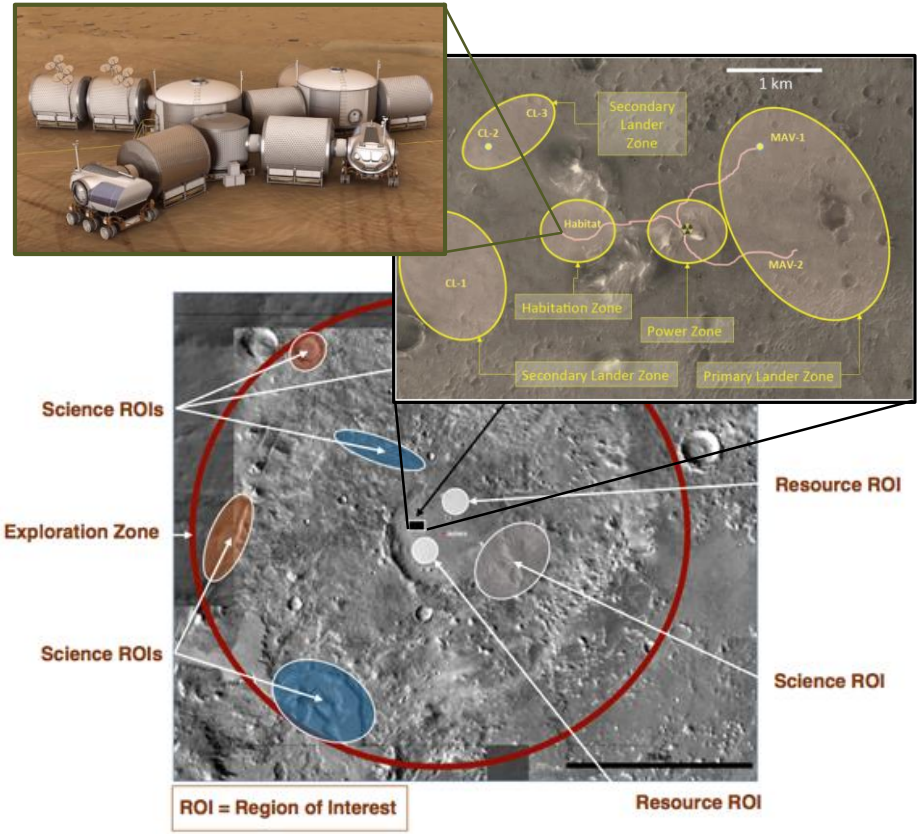
Landing Site Selection for Human Mars Missions

- **Early 2015**: NASA HEOMD and SMD jointly begin activities to focus efforts on identifying requirements for human landing site selection (HLS2)
- **April 2015**: ISRU and Civil Engineering Working Group (ICE-WG) formed
  - Goal: identify resource abundance, quality, and accessibility requirements and data needs for informing HLS2. Identify capabilities that are key to establishing sustained human presence on Mars
- **April 2015**: Human Exploration Science Objectives Science Analysis Group (HSO-SAG) formed
  - Goal: define options and priorities for scientific objectives for human Mars mission campaigns. Define criteria that could be used to identify science sites of interest for future human exploration
- **June 2015**: Open call for landing site candidates released. Includes definition of an "Exploration Zone" – an area containing a landing site and regions of interest
- **October 2015**: NASA holds First Mars Human Landing Site/Exploration Zone Workshop. 47 Exploration Zone candidates proposed.



Exploration Zone – Working Definition

- 100km radius site at latitude band: ±50°
- Contains:
  - **Habitation Site**: Flat, stable terrain for emplacement of infrastructure, located ≤5km from landing site location
  - **Landing Site(s):** Flat, stable terrain, low rockiness, clear over length scales greater than landing ellipse
  - **Resource Regions of Interest**
    - One or more potential near-surface (≤3m) water resource feedstocks in a form that is minable by highly automated systems, and located within ~1-3km of ISRU processing and power infrastructure. Total extractable water should be ~100MT (supports ~5 missions)
    - Show potential for minable metal/silicon resources, mainly Fe, Al, and Si, located within ~1-2m of the surface
  - **Science Regions of Interest**
    - Related to Astrobiology, Atmospheric Science, and Geoscience



Exploration Zone in context

- Exploration Zone is ~200x larger than robotic mission landing ellipses
- Traverses between regions of interest greater than any distance previously travelled off-Earth

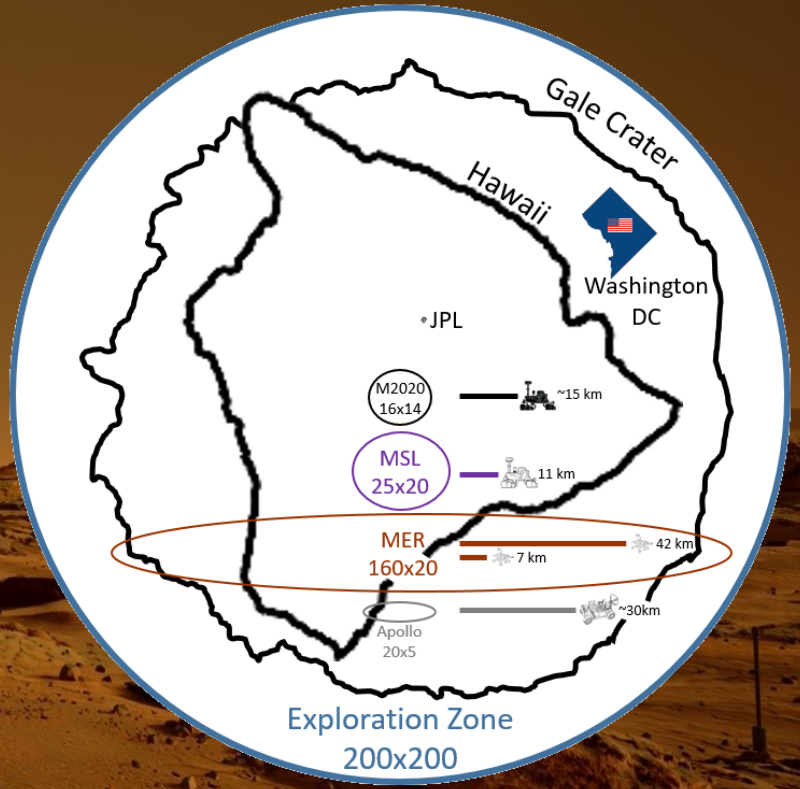
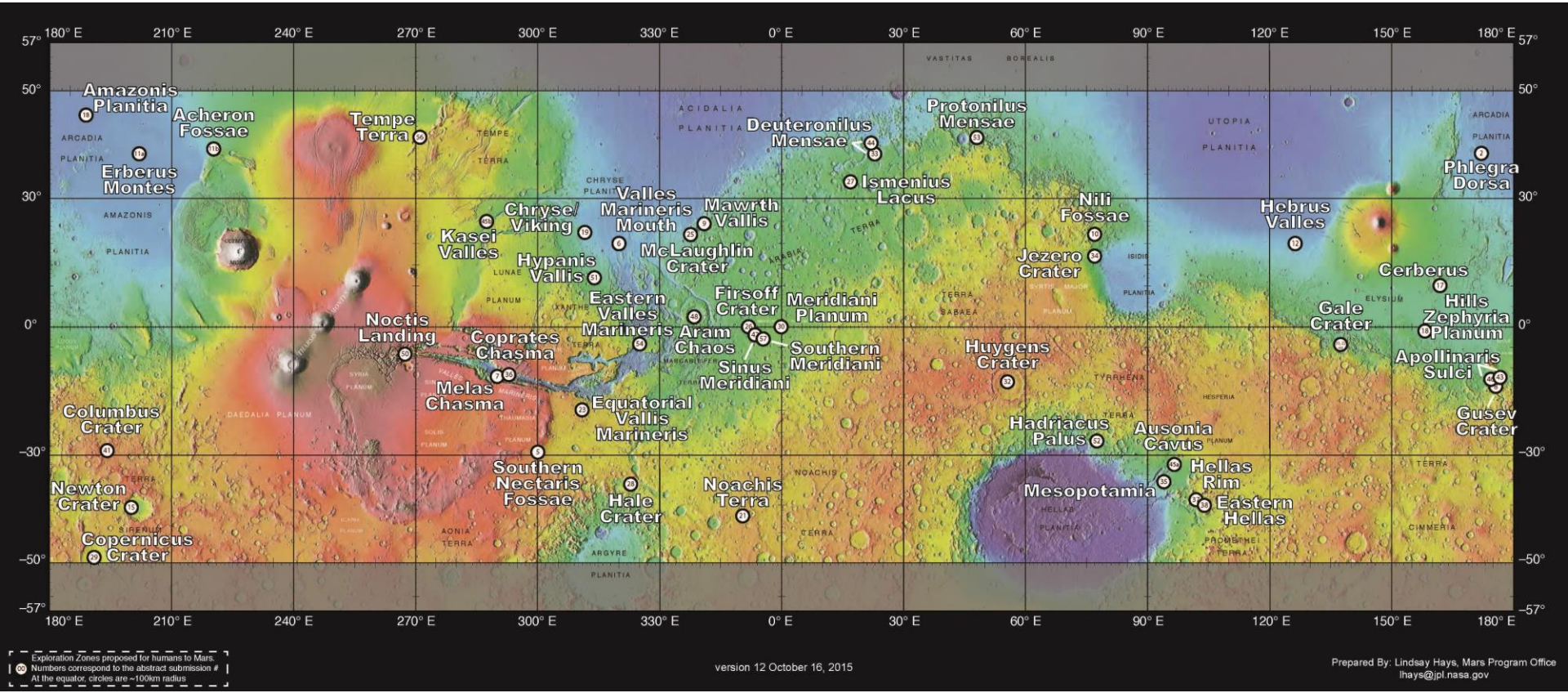


Image Credit: A. Nicholas

47 Exploration Zone Candidates

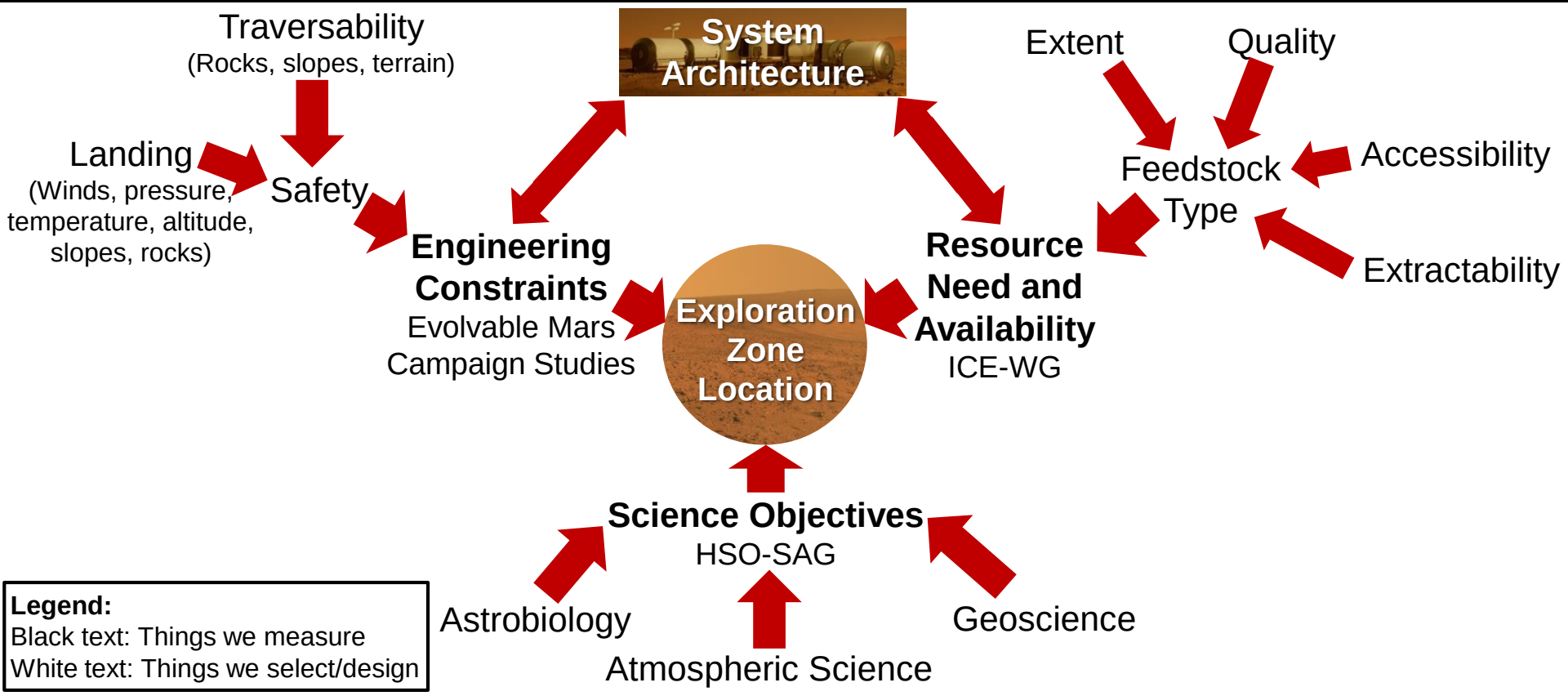


Exploration Zones proposed for humans to Mars.
Numbers correspond to the abstract submission #
At the equator, circles are ~100km radius

version 12 October 16, 2015

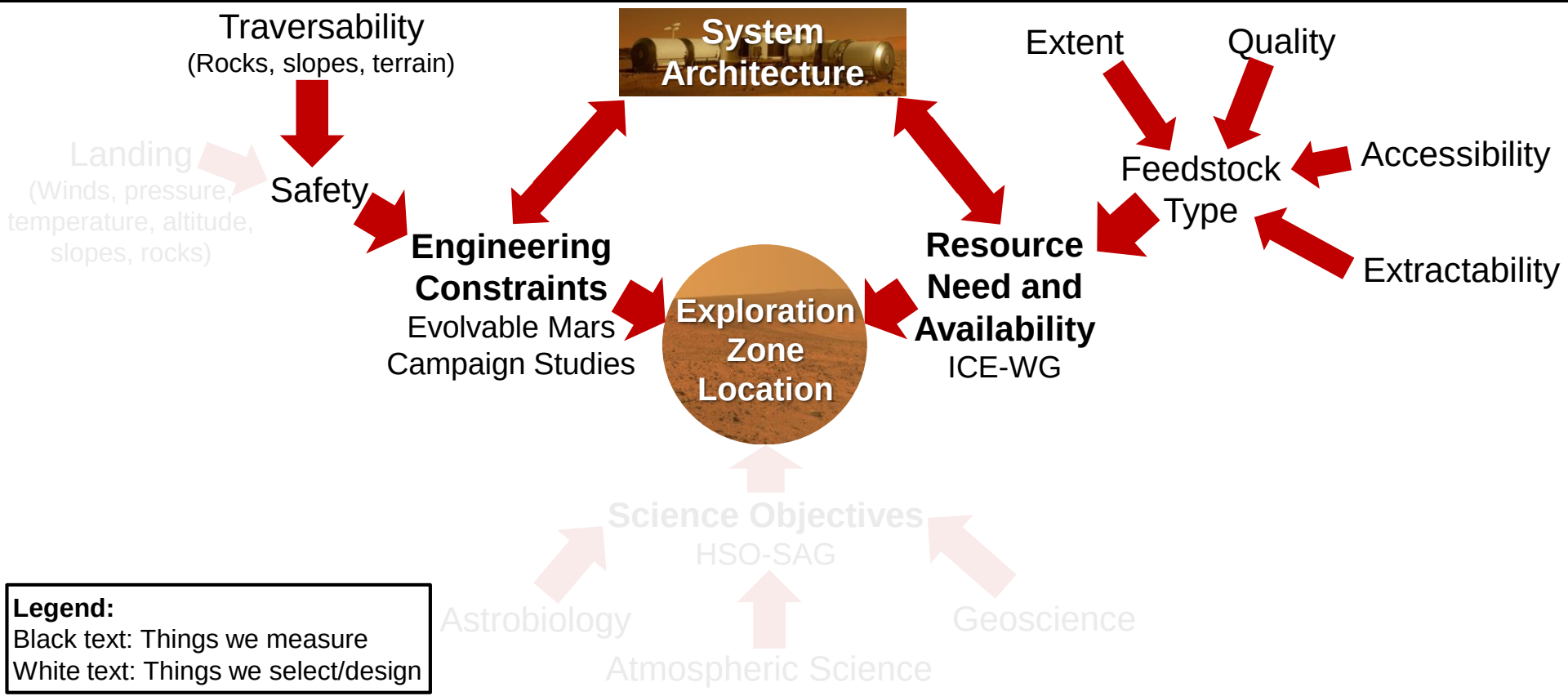
Prepared By: Lindsay Hays, Mars Program Office
lhays@jpl.nasa.gov

(A Subset of) the Human Landing Site Selection Tradespace



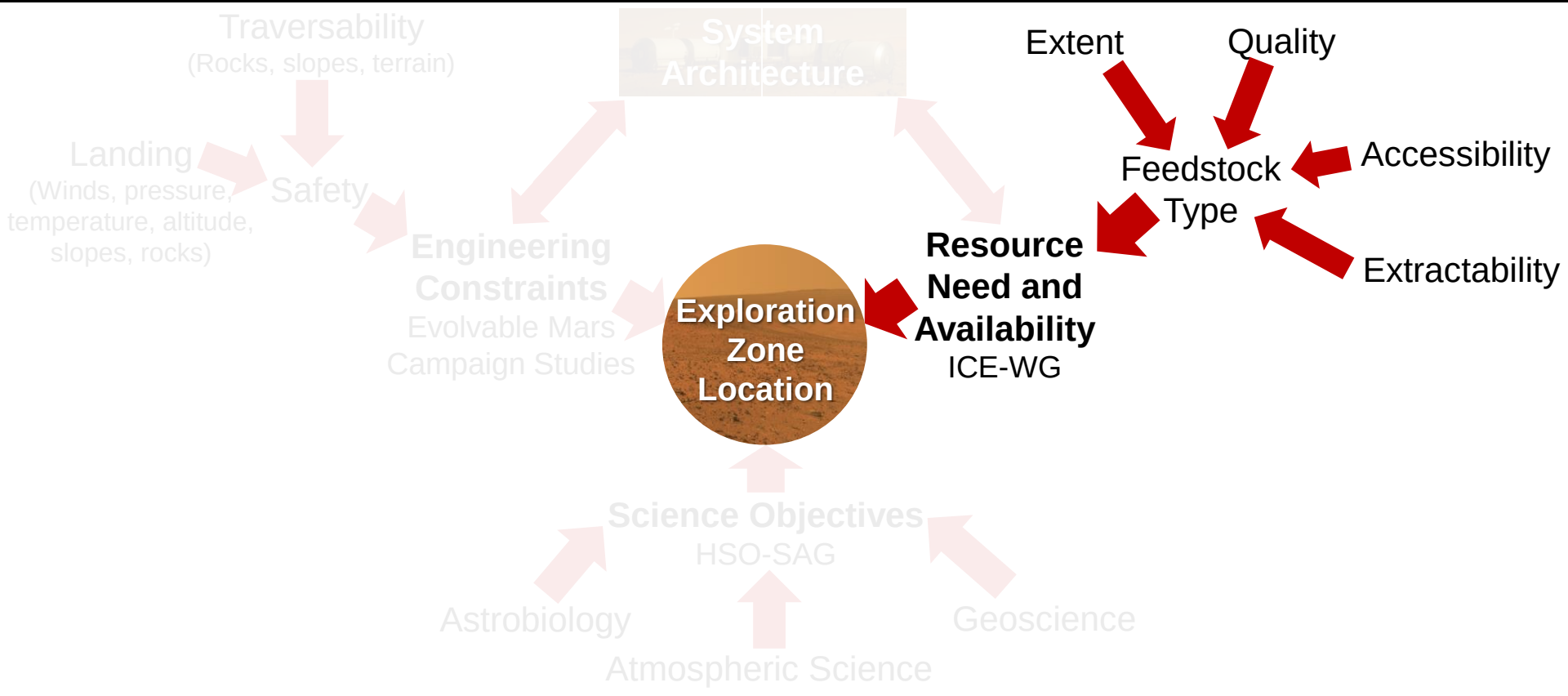
(A Subset of) the Human Landing Site Selection Tradespace

Particularly Relevant to ISRU and Off-Earth Mining



Legend:
Black text: Things we measure
White text: Things we select/design

Follow-on Activities from the 2015 Human Landing Site Workshop



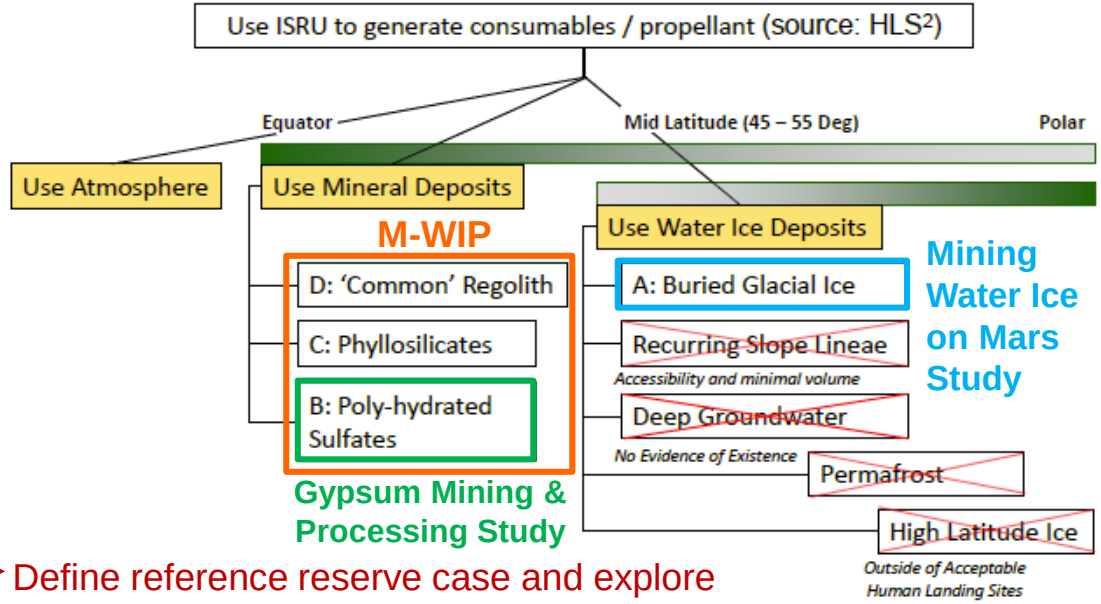
Overview of Follow-On Studies

Workshop Results:

- Imaging requests for HiRISE and CRISM instruments on MRO collected. Imaging currently underway
- Defined four most common types of water resource deposits for further exploration

NASA Sponsored Activities Since:

Jan–April 2016:	Mars Water ISRU Planning (M-WIP Study)
April–July 2016:	Mining Water Ice on Mars Study
Dec 2016:	AGU Mars Water Exploration Workshop
June–Aug 2017:	Gypsum Mining and Processing Study
June 2017–Oct 2018:	Mars Water Mapping Project

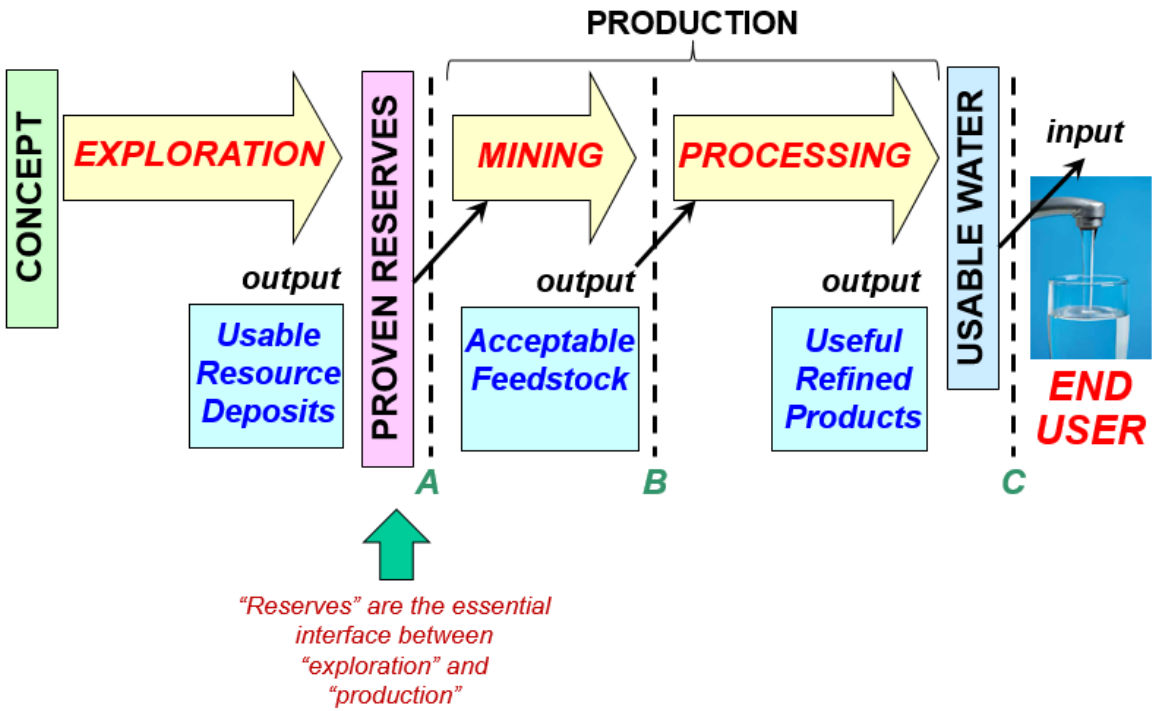


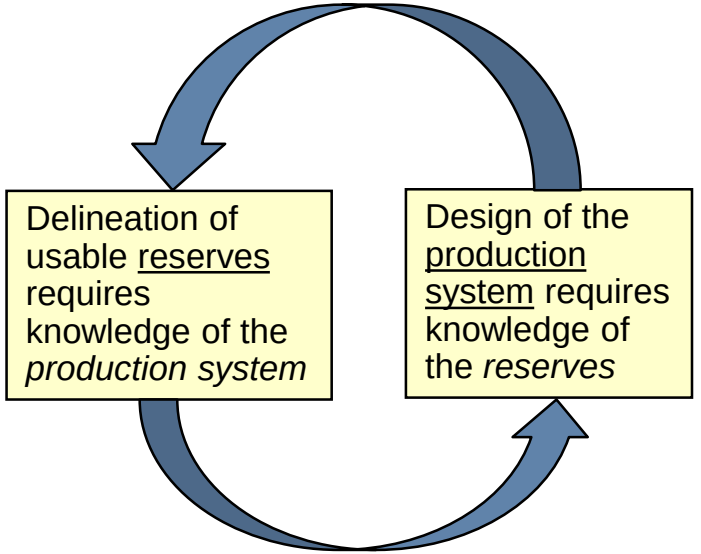
Define reference reserve case and explore feedstock mining and processing techniques

Better understand current distribution of water on Mars and the form in which it exists

Image Source: P. van Susante, M-WIP (2016)

M-WIP Study Overview

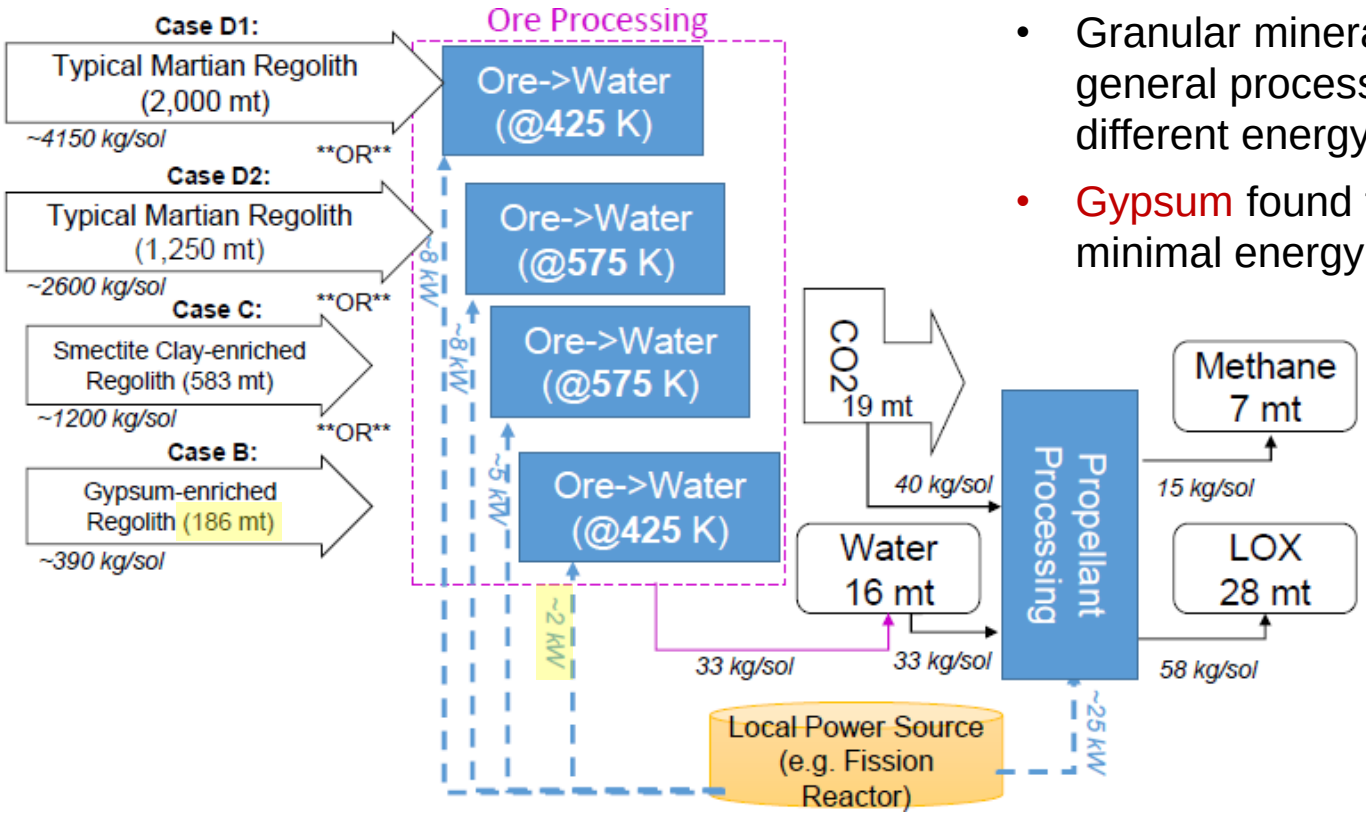




Because of this coupled relationship, both exploration and engineering need to advance together.

Source: M-WIP (2016)

M-WIP Study Results Overview



- Granular mineral deposits share same general processing strategy but have different energy implications
- Gypsum found to be the minimal mass, minimal energy feedstock

Source: M-WIP (2016)

M-WIP Study Results Overview

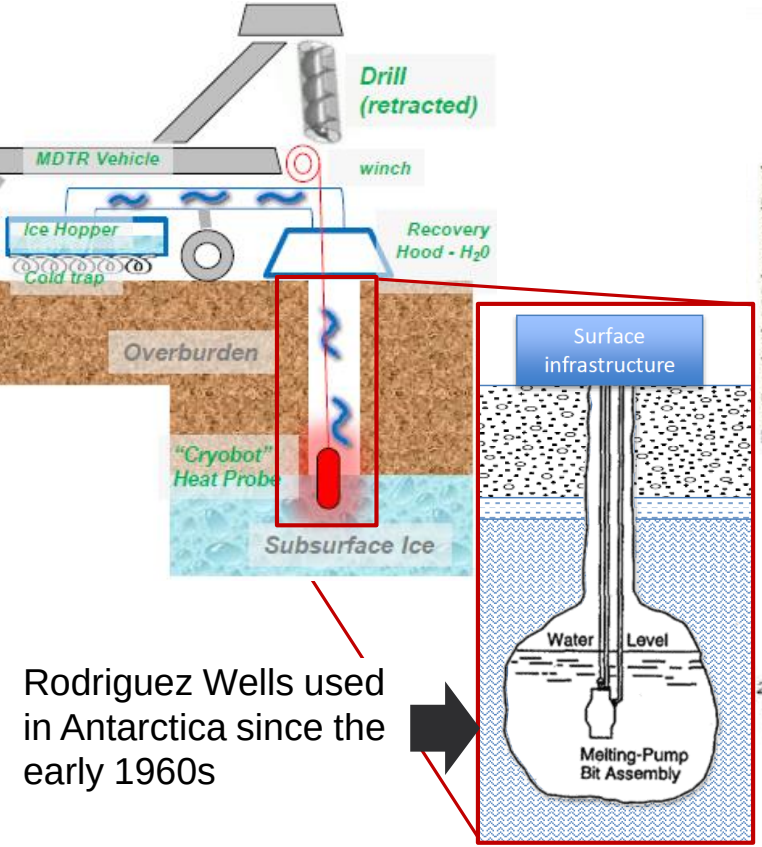
The ranked value of information for assessing potential for engineering viability

CASE	#1	#2	#3
A1 (Ice+open pit)	Thickness of overburden	Mechanical properties of overburden	Mechanical consistency of ore deposit
A2 (Ice+subsurface)	Mechanical consistency of ore deposit	*Thickness of overburden*	*Mechanical properties of overburden*
B (hydrated sulfate)	2D geometry/size of ore deposit	Mechanical consistency of ore deposit	Distance to processing plant
C (clay)	2D geometry/size of ore deposit	Mechanical consistency of ore deposit	Distance to processing plant
D (regolith)	Water concentration of ore deposit	Mechanical consistency of ore deposit	Chemical properties of ore deposit

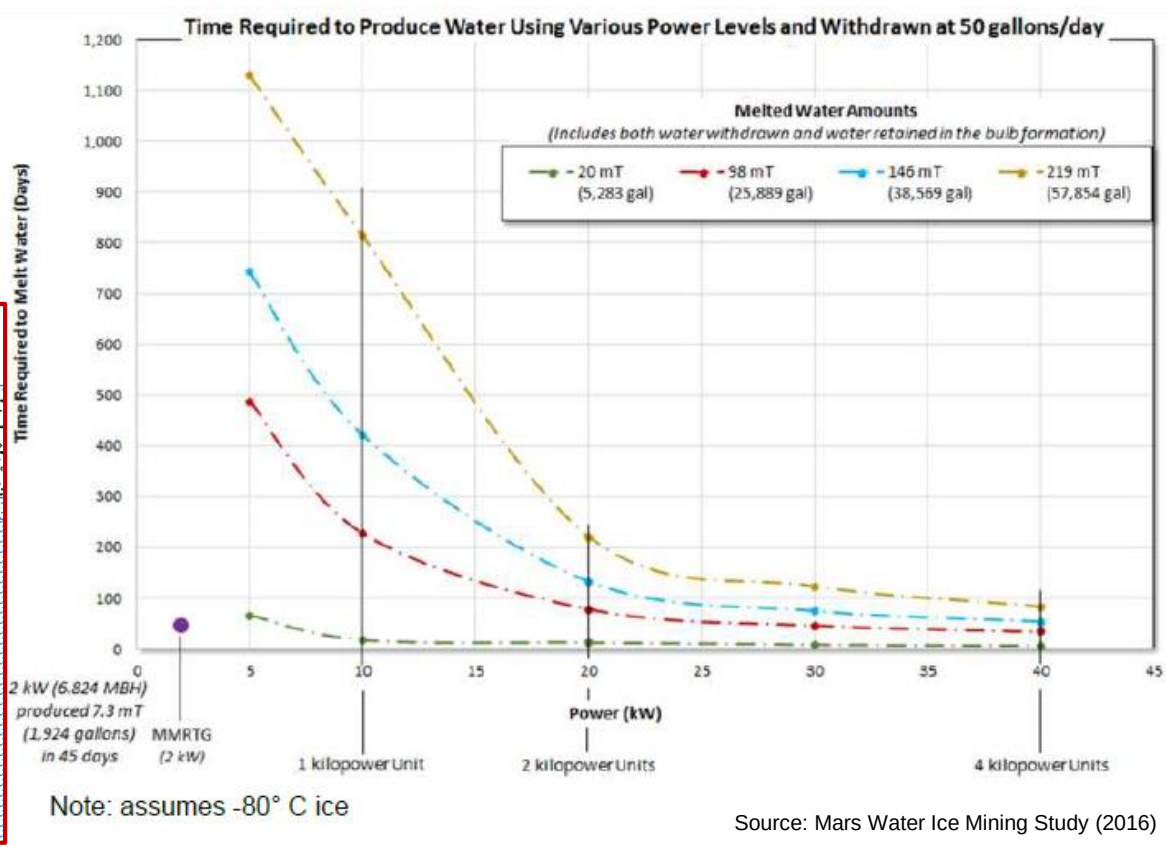
Information in cells shaded in blue are those for which **preliminary assessments can be made from orbit**, those in green **require data collected in situ**. For Case A2 only parameter #1 was ranked high priority, parameters #2 and #3 (in italics) were ranked medium priority.

Source: M-WIP (2016)

Mars Water Ice Mining Study Results Overview



Rodriguez Wells used in Antarctica since the early 1960s



Source: Mars Water Ice Mining Study (2016)

Gypsum Mining and Processing Study Overview

M-WIP found that gypsum was the most attractive mineral feedstock

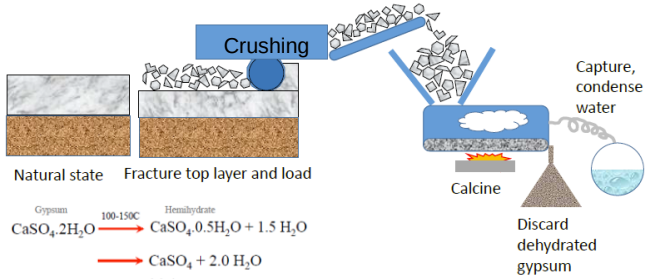
- However, M-WIP assumed granular materials
- Better understanding of processing bulk gypsum needed

This study:

- Explored gypsum mining and crushing approaches on Earth and suggested concepts for integrated gypsum processing systems on Mars
- Estimated optimal target grain sizes for minimal energy crushing and water extraction from gypsum

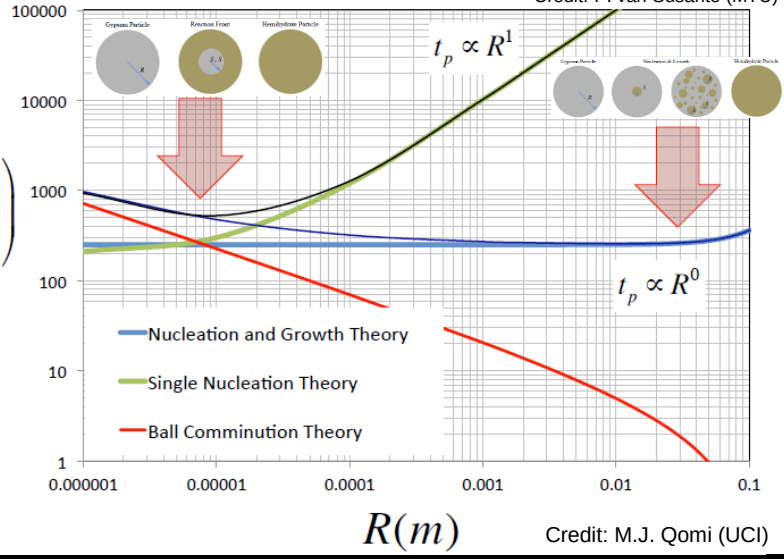
Forward Work by MTU:

- Mars-based gypsum mining & processing concepts developed. Plans underway for prototype development



Credit: P. van Susante (MTU)

$$E\left(\frac{KJ}{Kg}\right)$$



Credit: M.J. Qomi (UCI)

Mars Water Mapping Projects

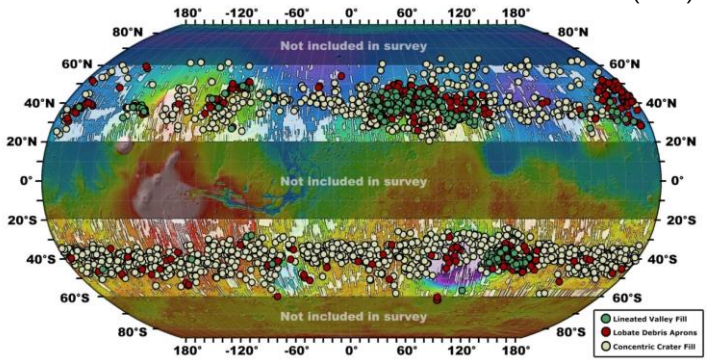
AGU Water Exploration Workshop (Dec 2016)

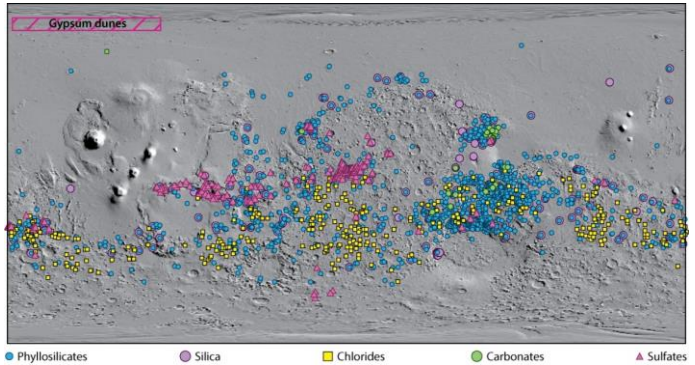
- Invited members of the Mars science community to discuss options for combining existing raw orbital datasets in a way that would help to identify sites or regions with high potential for productive water deposits
- Six candidate data products developed in real time. Top two selected for further development → RFP developed

Mars Water Mapping Projects (Ongoing)

- RFP Released June 2017. Requested proposals for two tasks:
  - **Task A – Subsurface Ice Mapping** (Arcadia Planitia Proof of Concept)
    - *Within a single 5-10° wide longitudinal swath from 0°-60°N latitude, generate a map that identifies potential locations of subsurface water ice at low- to mid-latitudes and characterizes the nature of the gradational boundary from regions of continuous ice to discontinuous ice, through to regions of no ice.*
  - **Task B – Hydrated Minerals (Global Map)**
    - *Develop algorithms to partially automate the processing of spectra of hydrated mineral detections. Use developed algorithms to generate global map of all existing near-surface hydrated mineral detections*
- Proposals currently under review. Maps expected late October 2018

Source: M-WIP (2016)





Source: M-WIP (2016)

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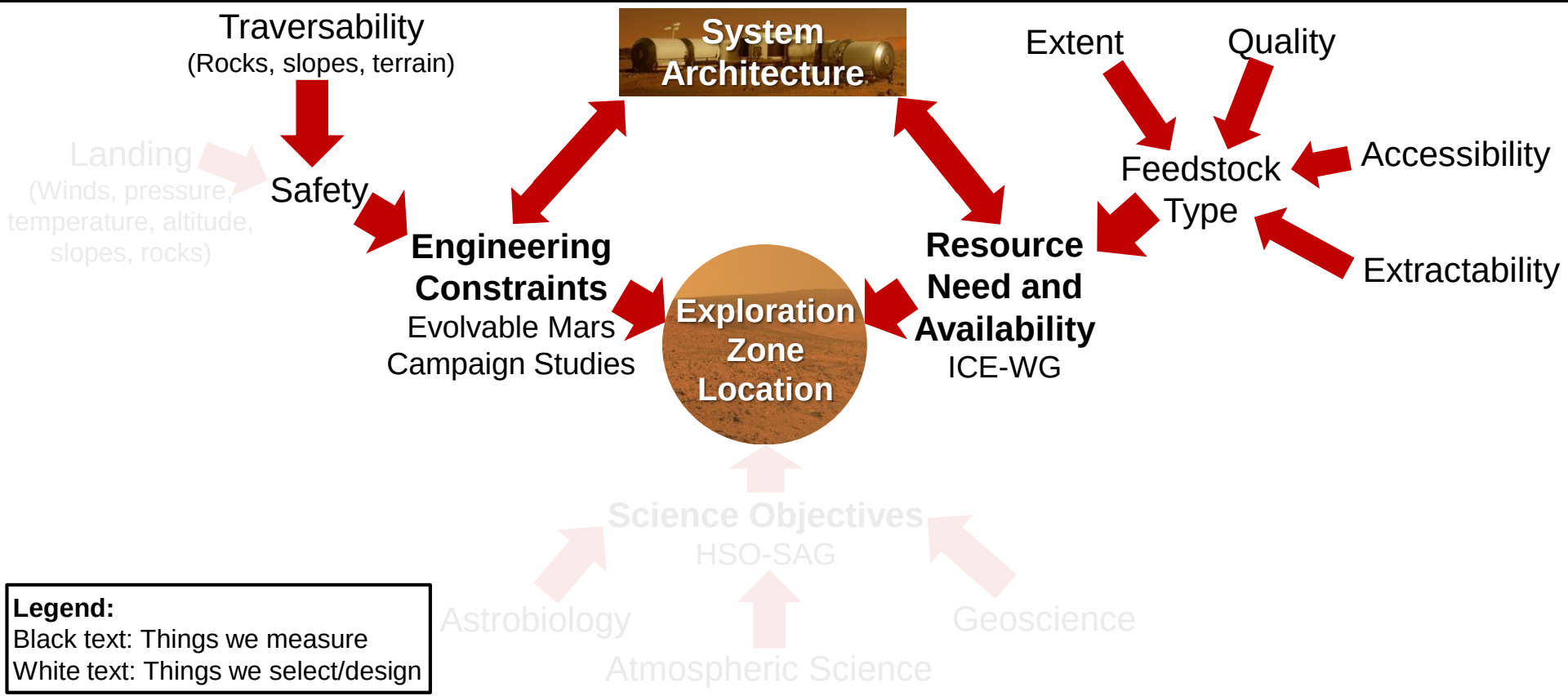
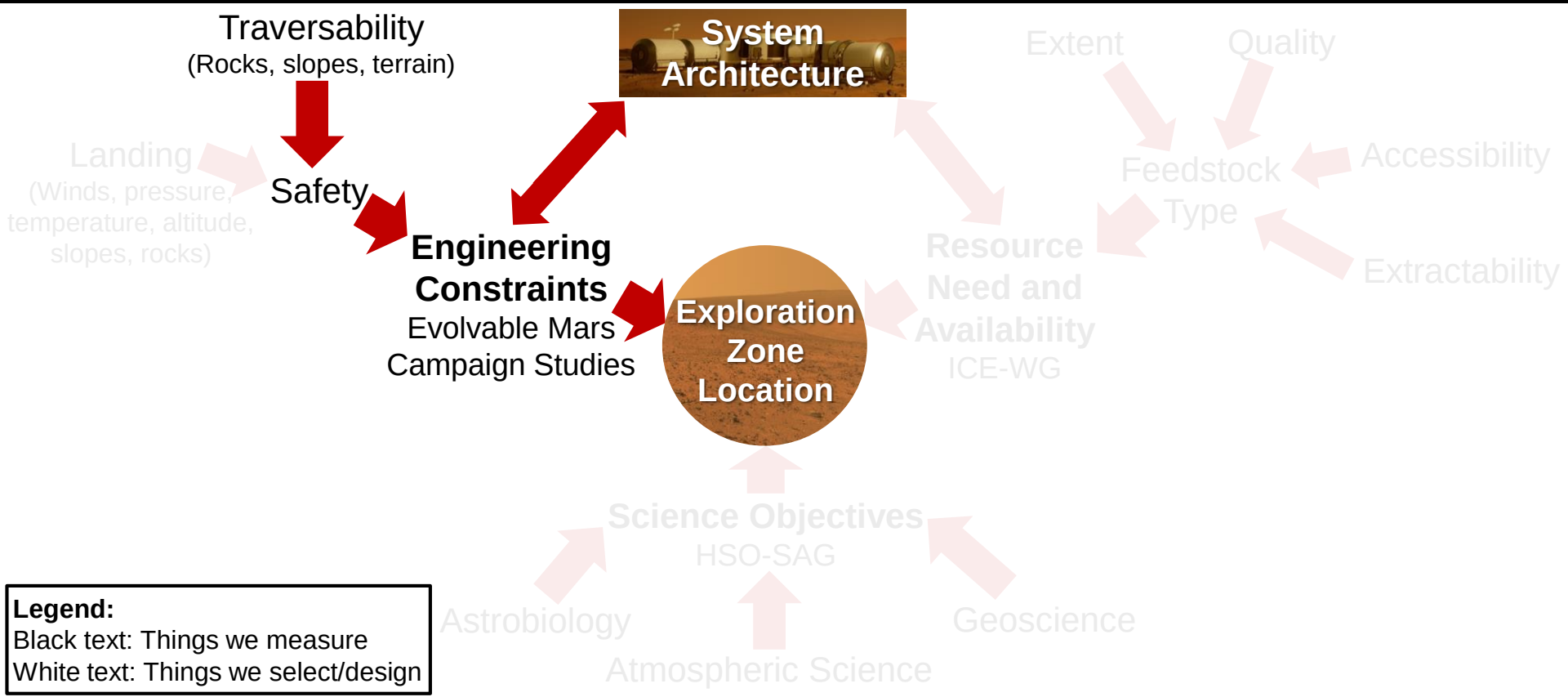


Legend:
Black text: Things we measure
White text: Things we select/design

Overview of Traversability and System Architecture Considerations



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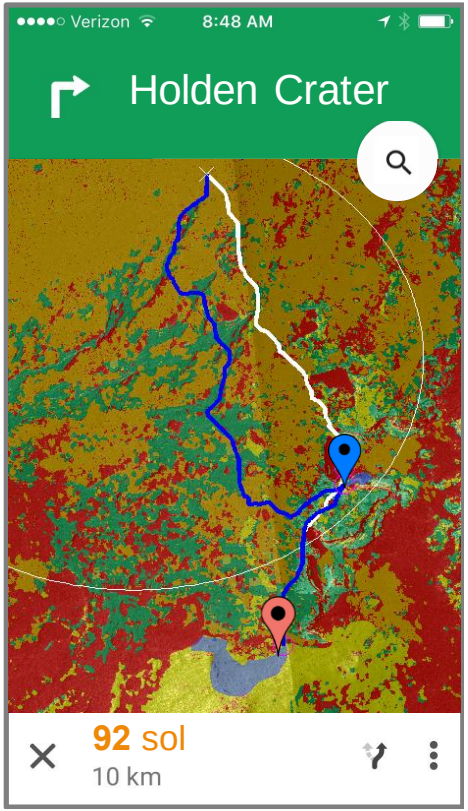
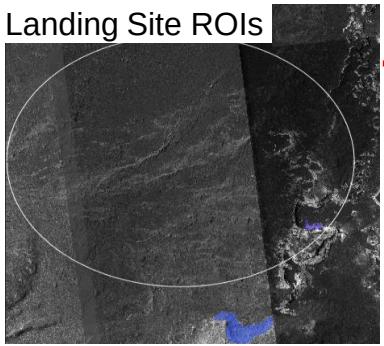
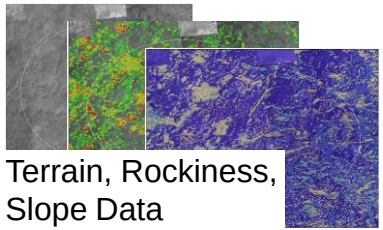
Traversability Analysis Capabilities used for Mars 2020

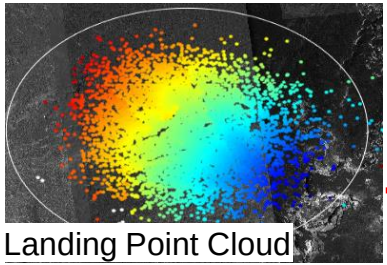


Landing Site ROIs





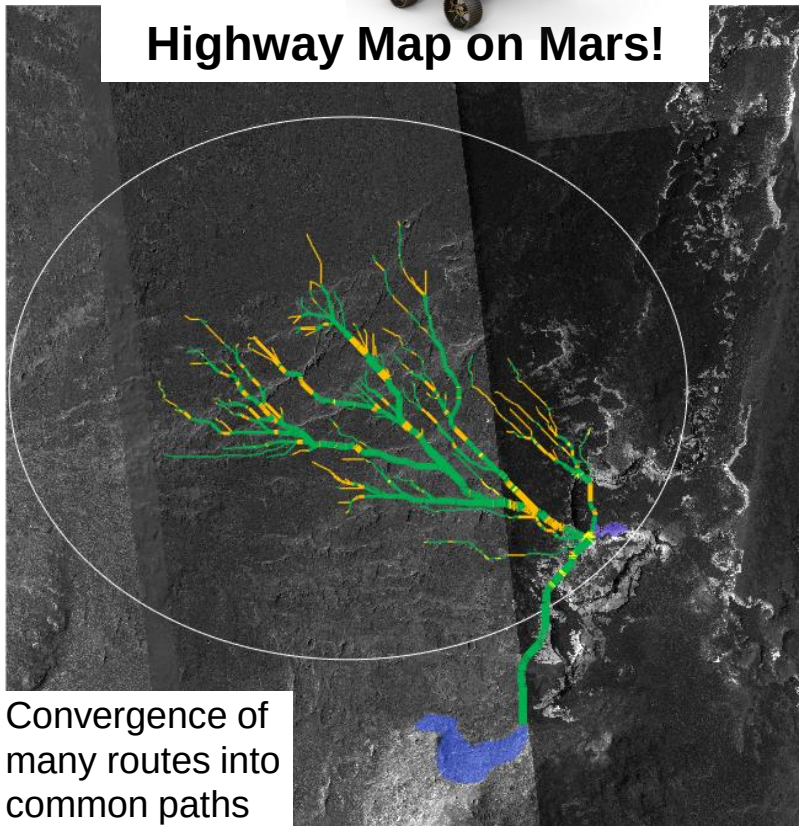
Terrain, Rockiness, Slope Data



Landing Point Cloud

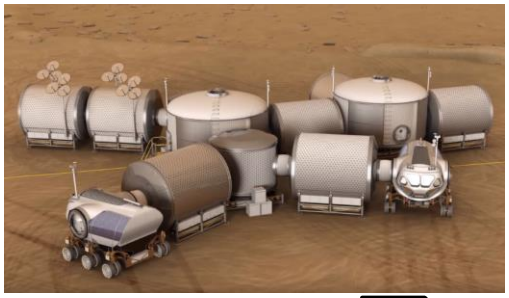
Monte-Carlo simulation

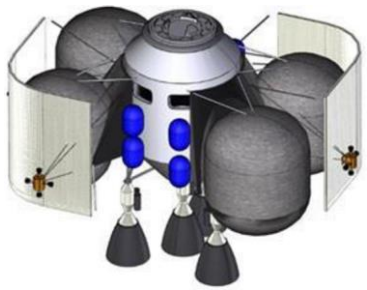
Highway Map on Mars!

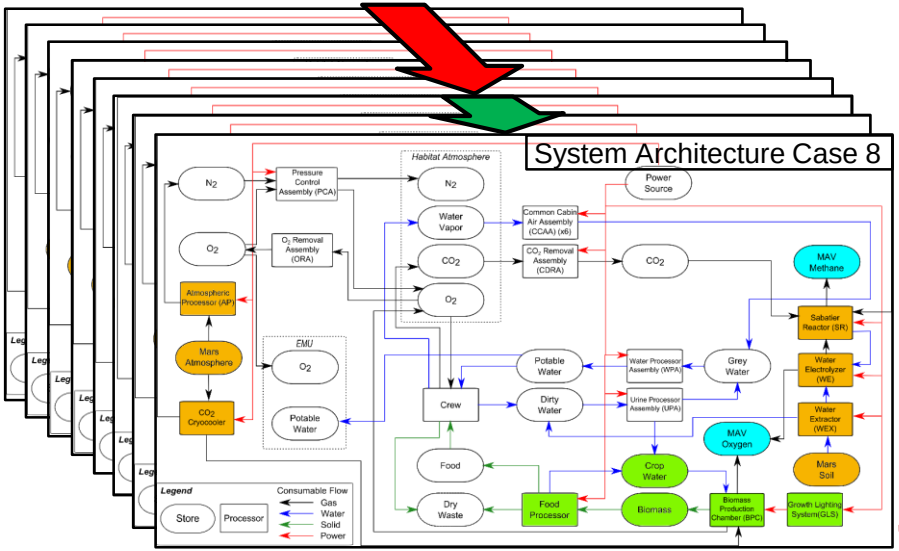


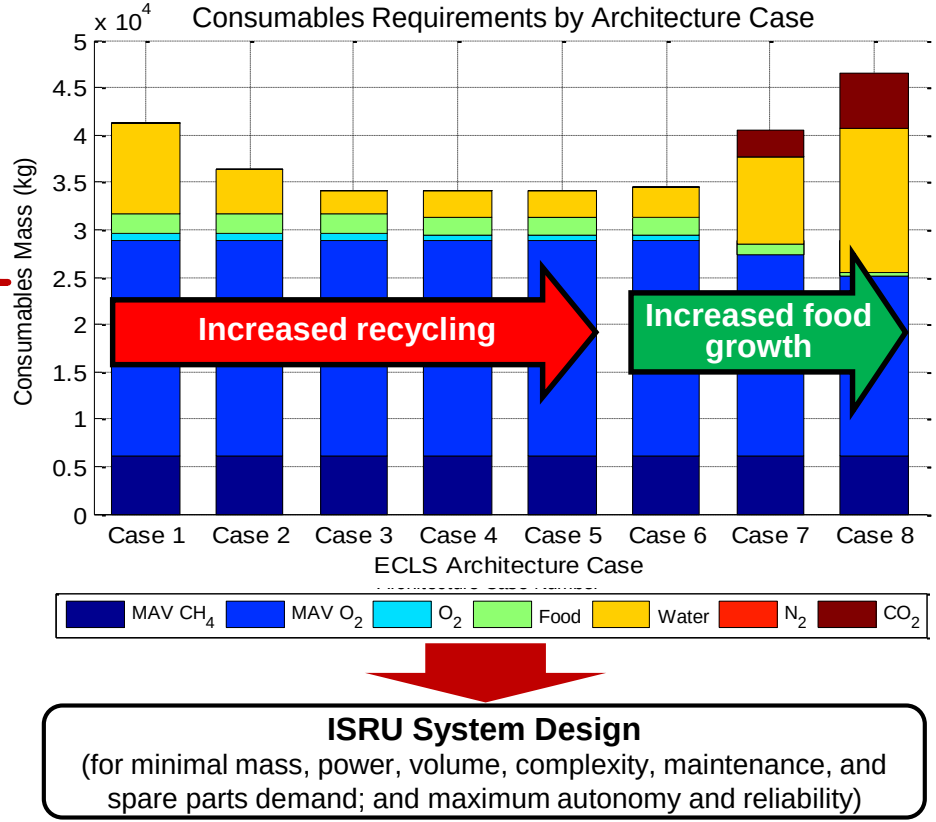
Convergence of many routes into common paths

Estimating Combined Resource Demands (Work ongoing)



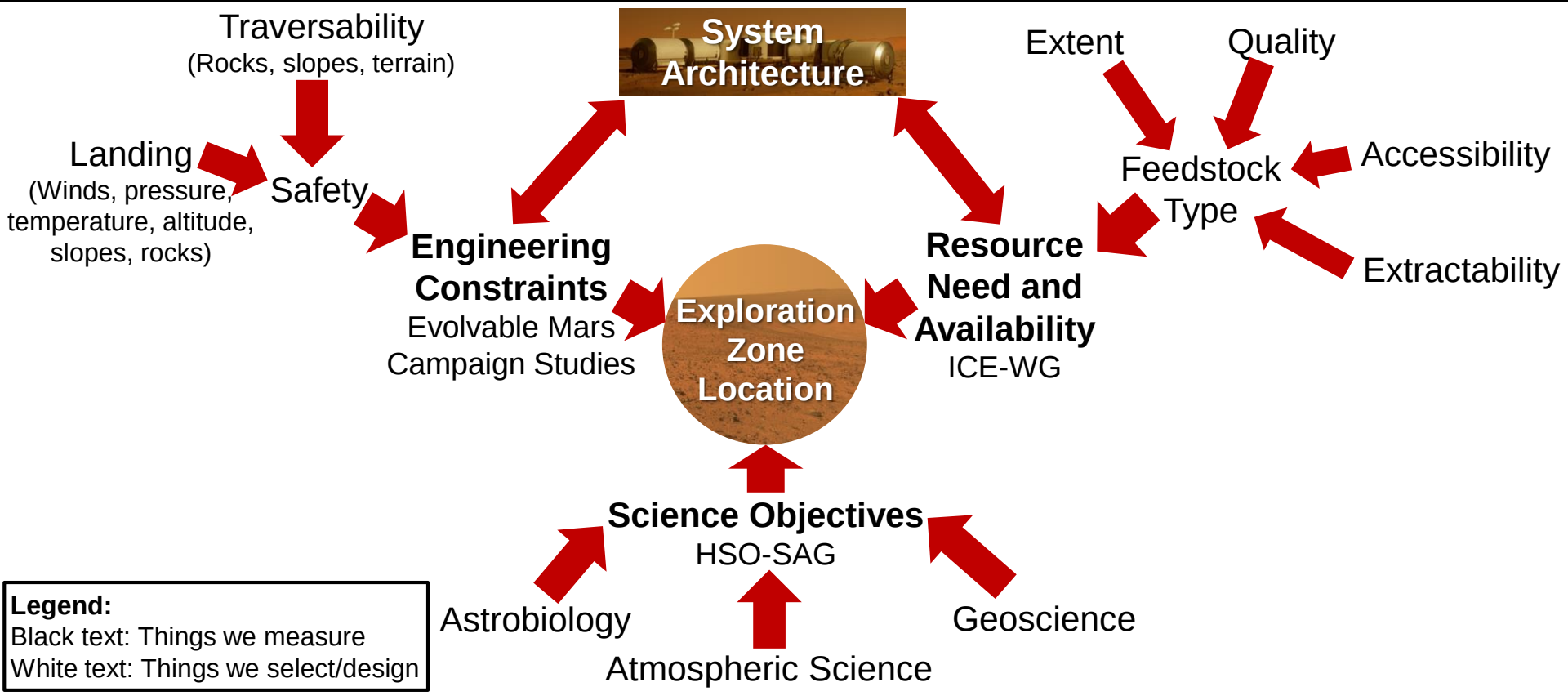


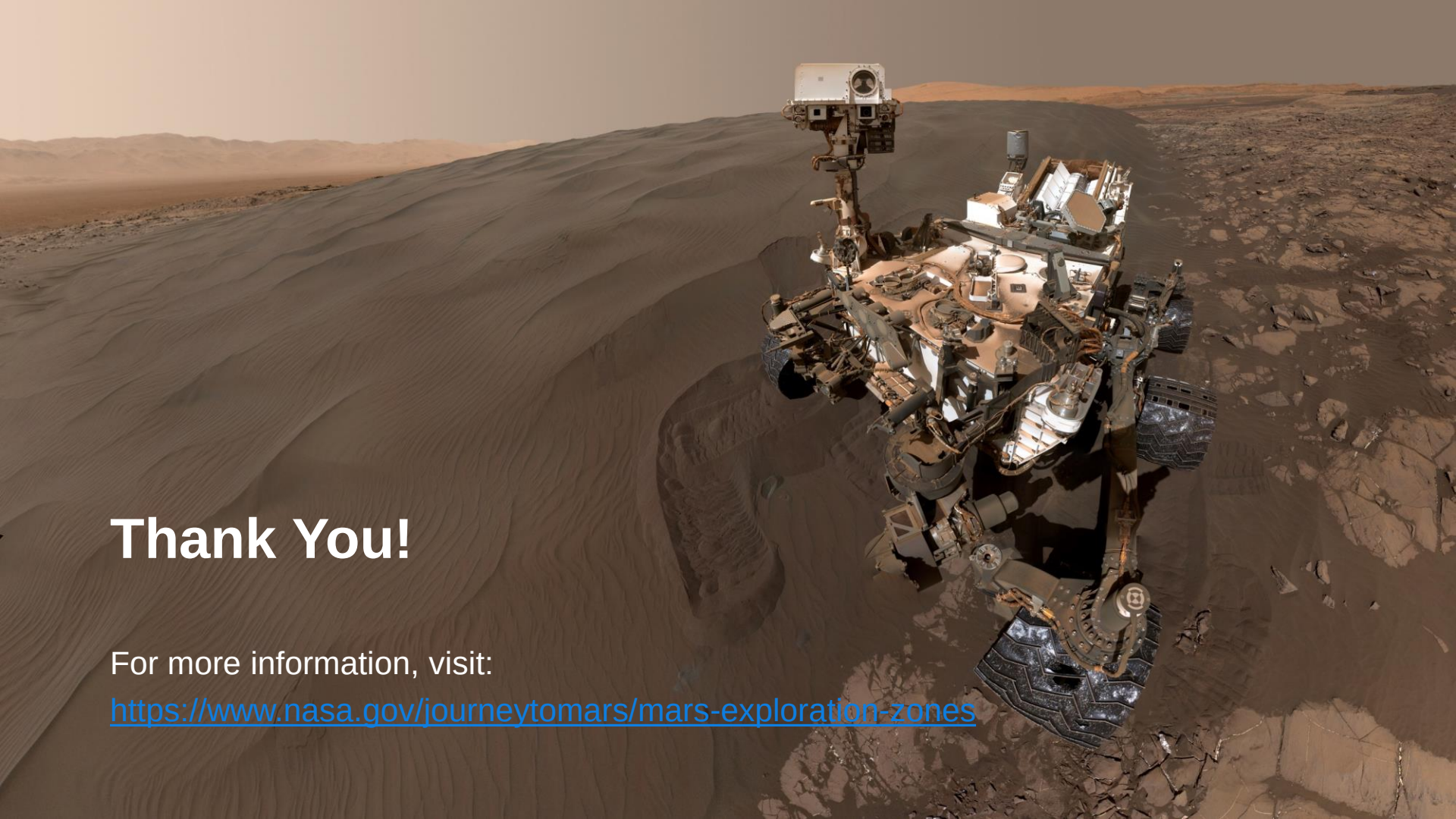




ISRU System Design
(for minimal mass, power, volume, complexity, maintenance, and spare parts demand; and maximum autonomy and reliability)

(A Subset of) the Human Landing Site Selection Tradespace





Thank You!

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